Fermi National Accelerator Laboratory

FERMILAB-Pub-82/83-EXP
7320.401
(Submitted to Phys. Rev. Lett.)

# $\psi'$ PHOTOPRODUCTION AT A MEAN ENERGY OF 150 GeV

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November 1982

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A measurement of the diffractive $\psi'$ photoproduction cross section is presented. The ratio of the $\psi'$ photoproduction cross section to the $\psi$ photoproduction cross section is found to be $0.20\pm0.05$ at an average energy of 150 GeV. Using vector meson dominance, the ratio of $\psi'$-nucleon to $\psi$-nucleon cross sections is $0.75\pm0.12$.

The production of the J/ψ meson by both real[1-3] and virtual[4] photons has been studied intensively since the discovery of this particle in 1974. Several models, such as vector meson dominance and photon gluon fusion, have been employed to describe the data. These models also make definite predictions for the production of the ψ' (3680). However, due primarily to the low cross section times branching fraction into di-leptons as compared to the ψ, only one measurement[2] of ψ' production exists and that is at an energy of 21 GeV.

We have measured the photoproduction of the ψ' at an average energy of 150 GeV using the Broad Band Photon Beam at Fermilab. Specifically, we observe the reactions

$$\gamma + d \rightarrow \psi' + X \qquad \text{(a)}$$
$$\psi' \rightarrow \psi\pi\pi$$
$$\psi \rightarrow \ell\bar{\ell}$$

and

$$\gamma + d \rightarrow \psi' + X \qquad \text{(b)}$$
$$\psi' \rightarrow \ell\bar{\ell}$$

where $\ell(\bar{\ell})$ represents either an $e^-$ ($e^+$) or a $\mu^-$ ($\mu^+$). A sample of over 1800 photoproduced J/ψ mesons, detected in the same exposure, has already been reported [3].

The photon beam[3] struck a 41cm liquid deuterium target. Non-interacting photons traversed the detector, and deposited their energy in an integrating quantameter. Forward-going final states were detected in a multiparticle spectrometer, consisting of two analyzing magnets and 15 planes of multiwire proportional chambers. This spectrometer is described in detail elsewhere.[3]

Tracks are called "inner" tracks if they pass through the aperture of both analyzing magnets. "Outer" tracks passed through the first magnet but did not pass through the second magnet. The acceptance for inner (outer) tracks was ± 35mr (±85mr). The momentum resolution of an inner (outer) track was $\Delta p/p = 0.015\% \; p$ (0.045% p). A fly's-eye array of lead glass blocks, preceded by a layer of blocks placed transversely, identified inner electrons. A lead-scintillator shower counter tagged outer electrons. The lead glass, hadron calorimeter (7 absorption lengths), and an additional 183cm of steel filtered hadrons and allowed a crossed scintillator hodoscope at the back of the detector to identify inner muons. An array of scintillators behind the yoke of the second analyzing magnet flagged outer muons.

The trigger was arranged to collect events with two muon candidates or two electron candidates, at least one of which was an inner track. The electron trigger had an additional requirement of less than 10 GeV of energy deposited in a hadron calorimeter at the end of the system. This requirement introduces biases into the $e^+e^-\pi^+\pi^-$ sample. A fast trigger processor, the M7[5], inspected each event to verify that there was at least one good track pointing at the target.

This paper describes an analysis of 4 charged track events for reaction 1a and two charged track events for reaction 1b. Events are used only if they contain no additional particles besides those required to make the $\psi'$ combination of interest.

Therefore the cross sections presented here do not represent inclusive cross sections, but are mainly "diffractive" cross sections.

Four track events are candidates for $\psi'$ if they have a net charge of zero, a vertex within the target volume, and two well-identified leptons of the same kind but opposite charge. Fig. 1a shows the dimuon spectrum obtained from 4 track events. In this figure, we have imposed the additional requirement that both muons be inner tracks. A clear peak of 20 events is seen at the $\psi$ mass. The background under this peak is significantly less than 1 event. Figure 1b shows the invariant mass of all 4 tracks for the events in the $\psi$ peak of Fig. 1a. The tracks not identified as muons are given the pion mass. Figure 2 shows the total sample of four track $\psi'$ candidates including events with both electron and muon and both inner-inner and inner-outer dilepton topologies. The total sample contains 26 events with a background of less than 1 event.

The acceptance for these events is calculated based on a diffractive production mechanism where the $\psi'$ carries off the full energy of the incoming photon. The exponential t-slope for the scattering is taken to be 4 which is consistent with the mean t-value observed and is similar to the slope obtained in this experiment for the $\psi$.[3] (The result is not particularly sensitive to the t-slope used in the acceptance calculation.) The dipion system is modeled to decay as an S-wave. The $\psi$ is taken to decay with a $1 + \cos^2\theta$ angular distribution (An

admixture of $\sin^2\theta$ would lower the cross section.)

The photon flux is obtained from the integrated quantameter current. The energy spectrum is measured by several independent methods described in reference 3.

Yields are corrected for spectrometer deadtime(1.25), pion absorption and decay in flight(1.11), detector and reconstruction inefficiencies(1.05), and triggering inefficiencies(1.33). The partial cross section obtained is

$$\sigma_{\gamma\to\psi'} \times B_1 \times B_2 = 93\pm24 \text{ pbarns}$$

where $B_1$ is the branching fraction of the $\psi'$ into $\psi\pi\pi$ and $B_2$ is the branching fraction for $\psi$ into $\mu^+\mu^-$ or $e^+e^-$. Using standard values for $B_1$ and $B_2$ (.33 and .07 respectively) we get

$$\sigma_{\gamma\to\psi'} = 6.0\pm1.5 \text{ nb/nucleon}$$

It must be remembered that this is a cross section for forward exclusive production and therefore represents diffractive rather than inclusive $\psi'$ production. The average energy of this determination is 150 GeV. The statistics are clearly too poor to make any statement about the energy dependence of the cross section. The average t-value is $0.23\pm0.07$ GeV$^2$, for events with t less than 1.0 GeV$^2$. This is consistent with the average value for $\psi$ production calculated from the data of reference 3.

Figure 3 shows the mass spectrum of exclusive dimuon events in the invariant mass region above the $\psi$. A suggestion of a peak is seen in this distribution. If the 6 event excess in the dimuon spectrum is assumed to represent $\psi'$ production, it

corresponds to a cross section of

$$\sigma_{\psi'} = 6.0 \pm 2.5 \text{ nb/nucleon}$$

where we have used the value .009 for the $\psi'$ branching fraction into $\mu^+\mu^-$ (or $e^+e^-$). This cross section is quite consistent with that obtained from the 4-track events.

The cross section obtained for the $\psi'$ should be compared with that obtained for the $\psi$ over this energy range (ref. 3).

$$\sigma_{\psi'}/\sigma_{\psi} = 0.20 \pm 0.05.$$

In vector-meson dominance models, the photoproduction of a vector meson, V, is related to Vp elastic scattering

$$\frac{d\sigma}{dt}(\gamma p \to Vp) = \frac{|p_V^*|^2}{|p_\gamma^*|^2} \frac{e^2}{f_V^2} \frac{d\sigma}{dt}(Vp \to Vp) \qquad (2)$$

where $p_x^*$ is the three momentum of x in the xp center of mass frame and $e^2/f_V^2$ is the coupling strength of the photon to V. By employing the optical theorem and by assuming the coupling strength on the photon mass shell is equal to the coupling constant measured from $e^+e^-$ collisions, we obtain

$$\frac{d\sigma}{dt}(\gamma p \to Vp)\Big|_{t=o} = \frac{3}{16\pi\alpha} \frac{\Gamma(V \to e^+e^-)}{M_V} \frac{|p_V^*|^2}{|p_\gamma^*|^2} \sigma_{tot}^2(Vp)(1+\alpha_V^2) \qquad (3)$$

where $\alpha_V^2$ is the square of the ratio of real to imaginary amplitudes for Vp elastic scattering. Using equation 3 we are now able to determine the ratio, R, of total cross sections of the $\psi'$ to the $\psi$:

$$R = \frac{\sigma_{tot}(\psi' p)}{\sigma_{tot}(\psi p)} = 0.75 \pm 0.12 \qquad (4)$$

where we take the leptonic widths of the $\psi$ and $\psi'$ to be 4.8±.6 Kev[6] and 2.1±.3 Kev[7] respectively and assume that the t-slopes and the ratio of real to imaginary amplitudes for the $\psi$ and $\psi'$ are equal. Both electron and muon events are used in this determination. The quoted error includes the statistical error from the measurement and the error on the leptonic widths only.

If we apply the same analysis to the results of reference 2, we find a similar value of R= .82±.16 at an energy of 21 GeV. By averaging the results of reference 2 with the results of this experiment, an R ratio of .77±.10 is found. Although there are many assumptions (which increase the errors above the quoted statistical error) involved in applying VMD to extract this ratio, this is an interesting result. If we postulate that all total cross sections are just the sum of the individual quark amplitudes, we expect the ratio R to equal 1. We observe that R is roughly equal to $m_{\psi}^2/m_{\psi'}^2$. This is exactly the same scaling law for the total cross sections observed for two vector mesons of different flavors. Comparisons, such as this, of the interactions of the various radial states of vector mesons with hadronic targets can best be carried out with states containing heavy quarks. Radial excitations of states with light quarks are broad, rest on large backgrounds, and their branching fractions are poorly determined.

We wish to thank the staffs of Fermilab and the high-energy group of the University of Illinois for their support and cooperation. We would like to thank Nevis Laboratory for making

available to us those parts of the spectrometer which they constructed as well as for the loan of the lead glass array and Cornell University for the use of a 30D40 analyzing magnet. This research was supported in part by the U. S. Department of Energy.

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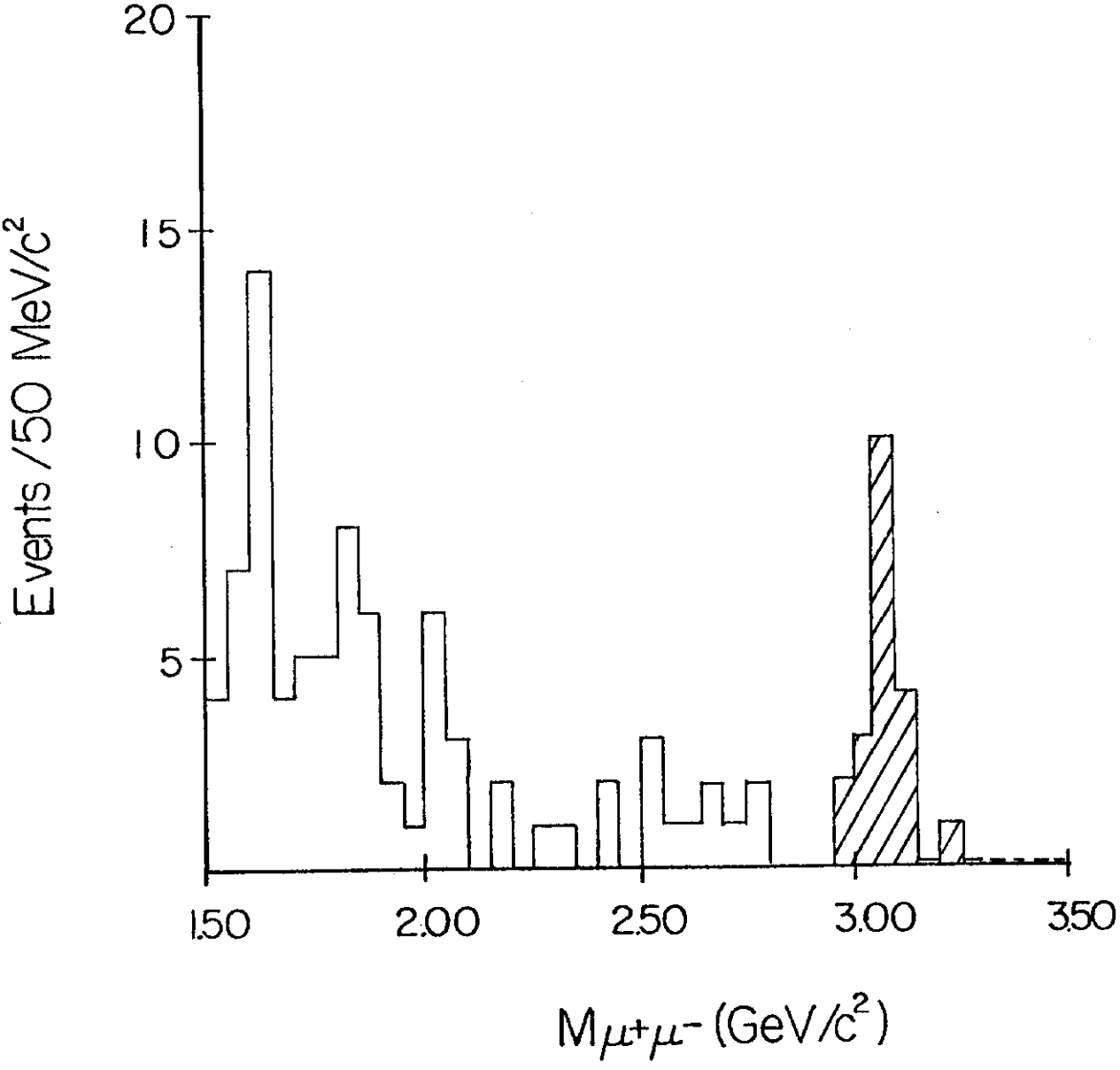


Fig. 1(a). $\mu^+\mu^-$ mass from four-track events with two well-identified muons.

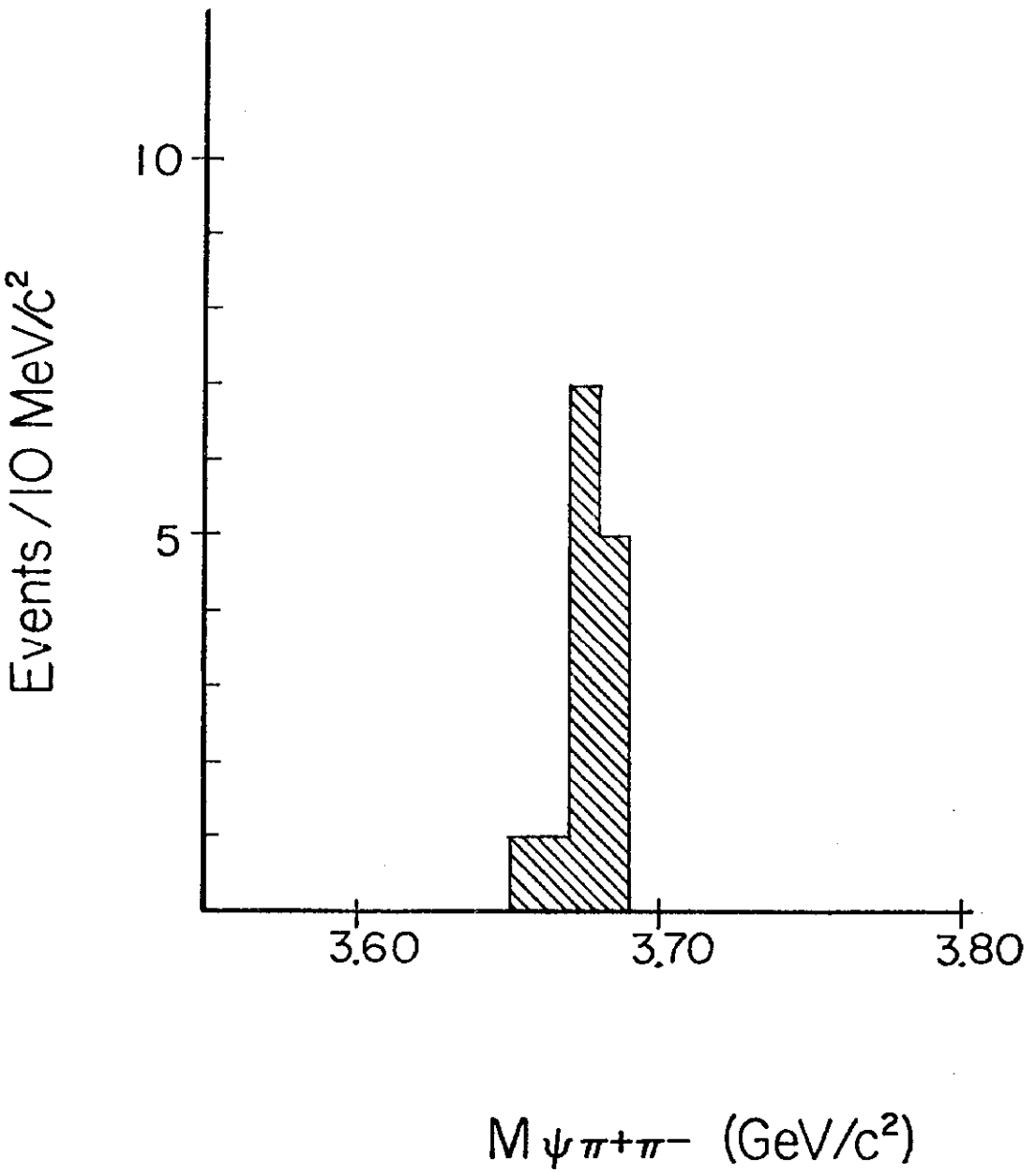


Fig. 1(b). $\mu^+\mu^-\pi^+\pi^-$ invariant mass for four-track events where $M_{\mu^+\mu^-}$ is between 2.9 and 3.3 GeV/$c^2$.

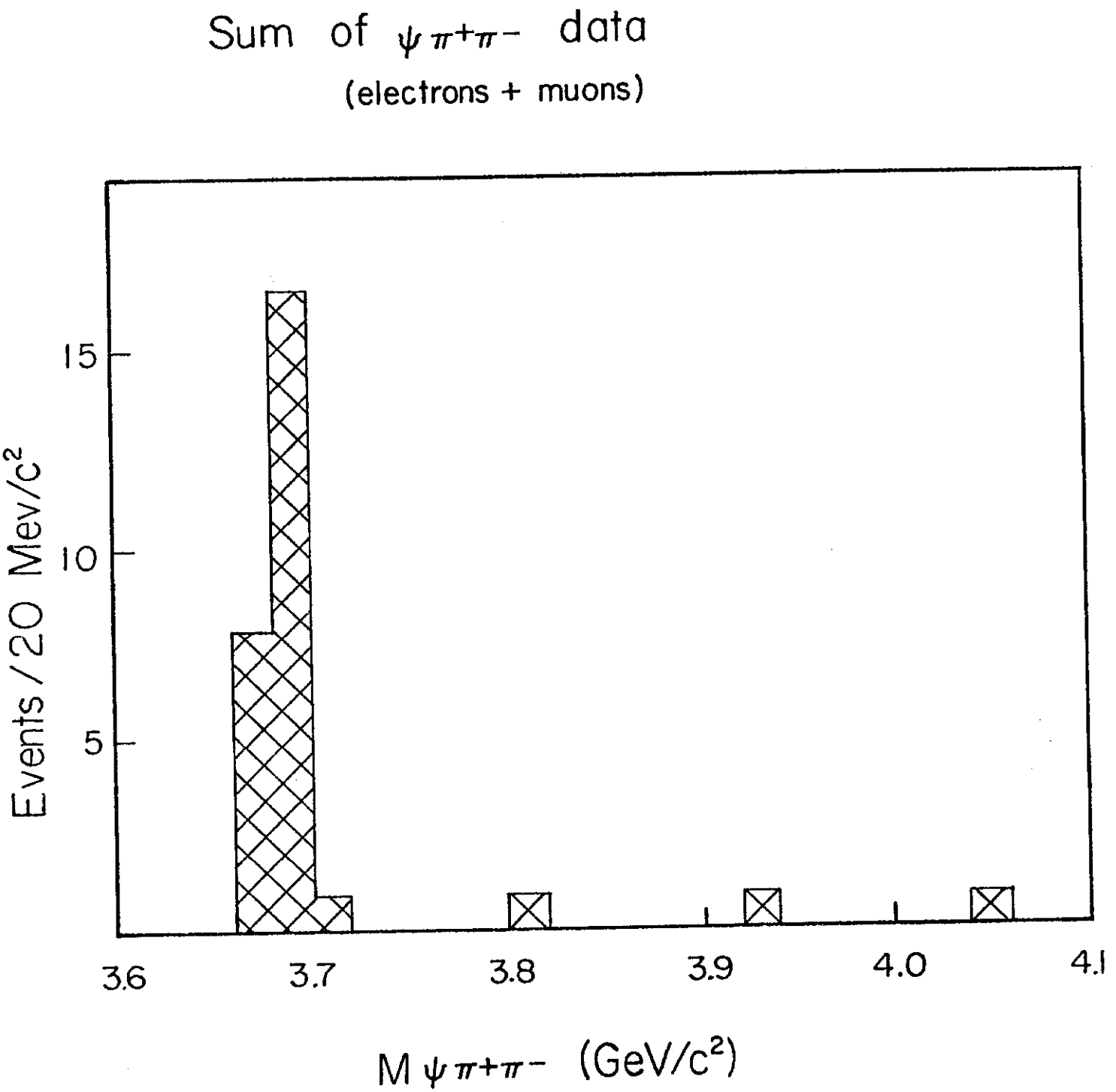


Fig. 2. $\ell\bar{\ell}\pi^+\pi^-$ invariant mass for four-track events where $M_{\ell\bar{\ell}}$ is between 2.9 and 3.3 GeV/$c^2$.

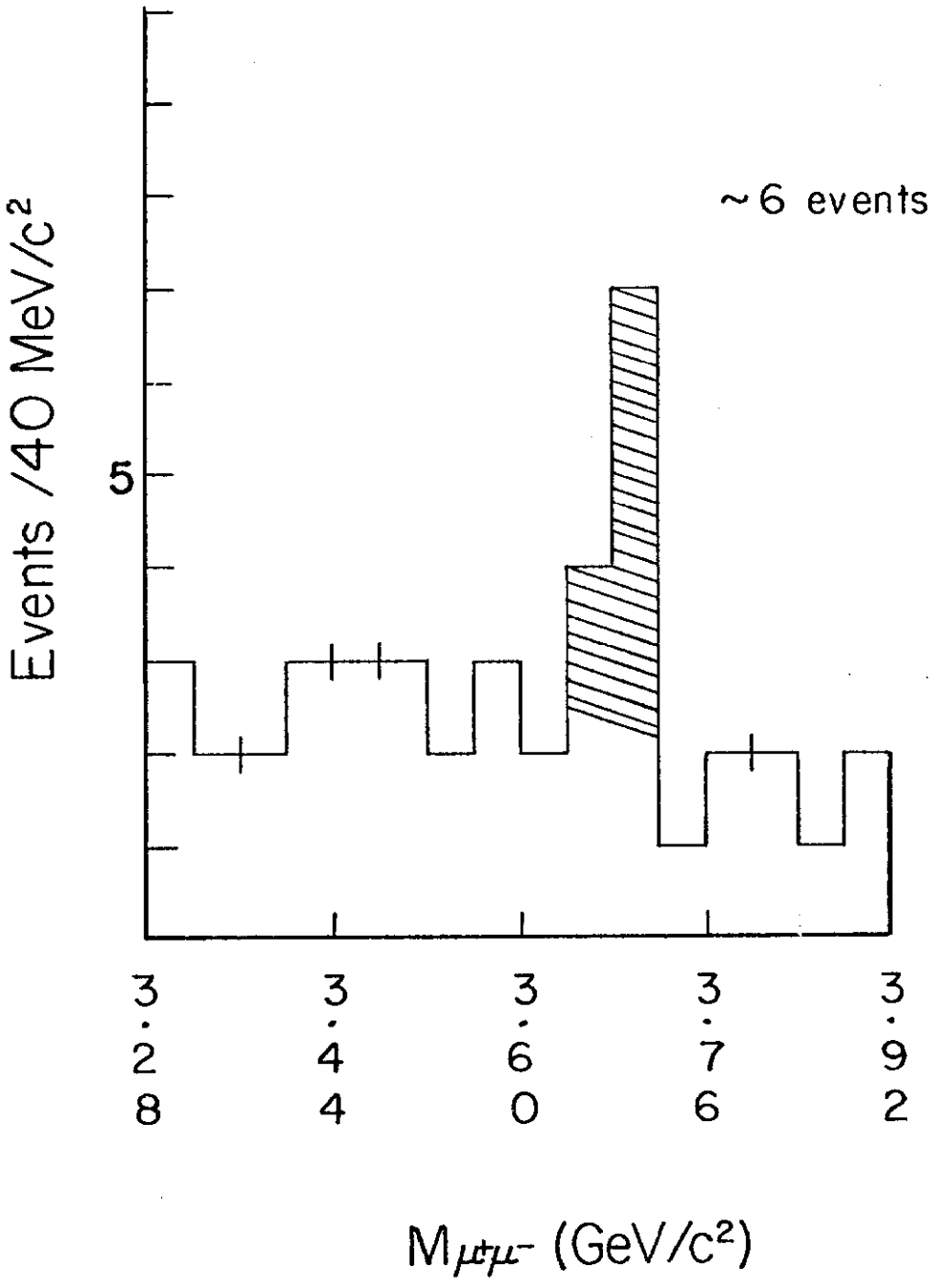


Fig. 3. $M_{\mu^+\mu^-}$ for two-track events in mass range above J/ψ.